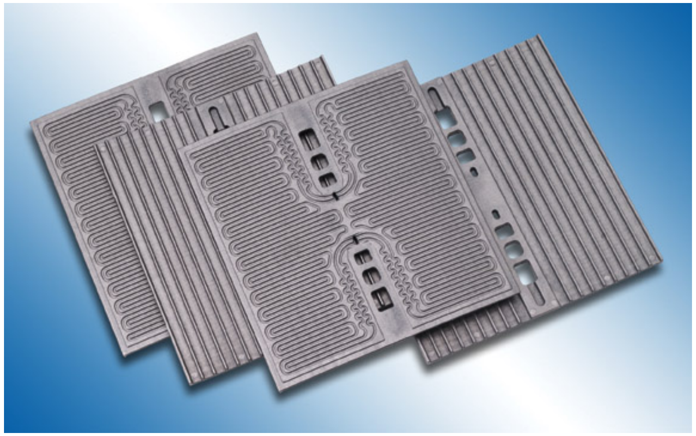
2008 DOE Hydrogen Program Review
Next Generation Bipolar Plates for Automotive PEM Fuel Cells



Orest Adrianowycz, Ph.D.
GrafTech International Ltd.

June 11th, 2008

Project ID # FC28

DOE Hydrogen Program

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GRAFTech International

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Overview

Project Timeline

- Start date: March 1st, 2007
- End date: February 29th, 2009
- Percent complete: 50%

Budget

- Total project: $2.9 MM
  - DOE share: $2.3 MM
  - Contractor share: $0.6 MM
- Spending FY07: $760K
- Budgeted FY08: $1,550K

Barriers (bipolar plates)

- A - Durability
  - Improved corrosion resistance
  - Decrease weight and volume
- B - Cost
  - Lower material & production costs
  - Increased power density
- C - Performance
  - Improved gas impermeability
  - Improved electrical and thermal conductivity

Collaborators

GrafTech International Ltd.
Primary Contractor

- Orest L. Adrianowycz, Ph.D. Principle Investigator
- Expanded graphite selection
- Preparation and testing of intermediate polymer-graphite composites
- Final graphite/polymer composition selection
- Bipolar plate manufacturing

Ballard Power Systems

- Warren Williams, Team Leader
- Flow field plate design
- Fuel cell stack assembly
- Durability and freeze-start testing
- Post-test analysis of composite plates

Huntsman Advanced Materials

- Roger Tietze, Team Leader
- Preliminary screening of high temperature resin formulations
- Mold release agents and flow additives for the resin formulations
- Scale-up of resin production for full-size plates manufacturing

Case Western Reserve University

- Professor Tom Zawodzinski, Team Leader
- High temperature membrane materials and testing protocol selection
- High temperature single cell testing of resin-graphite composite flow field plates
- Post-test analysis of high temperature single cell effluent

Program Objectives

Overall Project Objective

- Develop next-generation automotive bipolar plates based on an engineered composite of expanded graphite and resin capable of operation at 120 °C

Goals Year 1

- Develop graphite/polymer composite to meet 120ºC fuel cell operating temperature
- Demonstrate manufacturing capability of new materials to a reduced bipolar plate thickness of 1.6 mm

Goals Year 2

- Manufacture high-temperature flow field plates for full scale testing
- Validate performance of new plates under automotive conditions using a short (10-cell) stack
- Show viability of published cost target through the use of low-cost materials amenable to high volume manufacturing

Program Milestones/Go-No Go Decisions

Task	Milestones	Target Date	Status
1	**Expanded Graphite Material Selection**		
1.2.7	Final Graphite Flake Sources Selected	03/23/07	Complete
1.3.2.9	Graphite for resin evaluation Identified	05/29/07	Complete
1.3.3.9	Experimental Graphite Resin Evaluation Completed	01/02/08	In progress
2	**Resin Identification and Selection**		
2.7	Resin Formulations for Composite Studies Selected	05/21/07	Complete
3	**Small-Scale Composite Preparation and Evaluation**		
3.2.10	Resins for Single Cell Testing Selected	08/30/07	Complete
3.2.12	Contingency Point: Resins for Single Cell Testing Selected	08/30/07	Complete
4	**Machining and Embossment of Small-Scale Composites**		
4.3.5	Machined Plates Completed	10/12/07	Complete
4.5.2	Composites Embossability Characterized	01/16/08	Complete
4.6.5	Final Graphite, Resin and Processing Parameters Selected	03/17/08	Complete
5	**Single Cell Testing**		
5.10	Single Cell Testing Completed	03/13/08	In progress
6	**Design and Manufacture Full-size Bipolar Plates**		
6.5.7	Full Size Tool and Leak Check Device Ready	09/03/08	In progress
6.6.18	Full Size Plates Ready for Short Stack Testing	10/01/08	Not Started
7	**Short Stack Test of Full-size Plates**		
7.1.5	Short Stack Full Size Plates Ready for Testing	11/05/08	Not Started
7.3.3	Final Review of Short Stack Test Results Completed	02/20/09	Not Started
7.4.2	Stack Delivered to DOE	03/06/09	Not Started
8	**Economic Assessment of New Technologies**		
8.2	Economic Assessment Complete	12/16/08	Not Started

Approach

Task 1: Graphite Selection
- Raw Material Evaluation
- Intercalation Chemistry and Processing Optimization

Task 2: Resin Selection
- Resin Evaluation
- Resin Selection

Task 3: Small-Scale Composite Prep
- Develop Methods for Composite Plate Manufacturing and Testing
- Evaluate Thermal and Mechanical Properties
- Conduct Environmental Chamber Testing

Task 4: Composite Machining and Embossing
- Machined Plates for Single Cell Testing
- Validate Composite Properties
- Evaluate Small Embossed Test Plates

Task 5: Single Cell Testing
- Select High Temp Cell Components
- Develop Test Method for Leachates
- Perform Single Cell Testing and Analysis

Task 6: Design and Manufacture Full-size Bipolar Plates
- Design Flow Field Plate Molds
- Fabricate Full Size Embossing Die Set
- Manufacture Full-size Bipolar Plates

Task 7: Full-size Plate Short Stack Testing
- Short stack plate assembly
- Test Cells in Short-Cell Stack
- Post-Test Analysis
- Deliver Full Size Plate Stack to DOE

Task 8: Economic Assessment of New Technologies
- Perform economic assessment of the selected raw material and manufacturing processing

Flow Field Plate Functions

- Serves as a current collector
- Distributes fuel (typically hydrogen) and oxidant (typically air) uniformly over the cell active areas
- Facilitates water management of the membrane to keep it humidified
- Acts as an impermeable barrier to maintain the hydrogen gradient across the membrane necessary for high power output
- Provides some structural support for the stack
- Removes heat from the active area of the cells
- The most bulky component in the PEM fuel cell stack, by both weight and volume

DoE Targets for Bipolar Plate Performance

Characteristic	Units	Status 2005[a]	2010 Target	2015 Target
Cost[b]	\$/kW	10[c]	5	3
Weight	kg/kW	0.36	<0.4	<0.4
H_2 Permeation Flux @ 80 °C, 3 atm. (equivalent to <0.1 mA/cm^2)	$cm^3\ sec^{-1}\ cm^{-2}$	$< 2 \times 10^{-6}$	$< 2 \times 10^{-6}$	$< 2 \times 10^{-6}$
Corrosion	$\mu A/cm^2$	<1[d]	<1[d]	<1[d]
Electrical Conductivity	S/cm	>600	>100	>100
Resistivity[e]	Ohm cm^2	<0.02	0.01	0.01
Flexural Strength[f]	MPa	>34	>25	>25
Flexibility	% deflection at mid-span	1.5 to 3.5	3 to 5	3 to 5

(DoE Publication Table 3.4.14)

a This is the first year for which status is available. 2005 status is for carbon plates, except for corrosion status which is based on metal plates.

b Based on 2002 dollars and costs projected to high volume production (500,000 stacks per year).

c Status is from 2005 TIAX study and will be periodically updated.

d May have to be as low as 1 nA/cm if all corrosion product ions remain in ionomer.

e Includes contact resistance.

f Developers have used ASTM C-651-91 Standard Test Method for Flexural Strength of Manufactured Carbon and Graphite Articles Using Four Point Loading at Room Temperature.

Flow Field Plate Technologies Comparison

Technology	Advantages	Disadvantages
GRAFCELL® Resin Impregnated Flexible Graphite	Chemically inert Electrical conductivity Contact resistance Thermal conductivity Thin Lower Cost Proven performance	Strength Not as thin as metals
Graphite-Filled Polymers	Known fabrication techniques Molded-in flow fields Low Density	Thermal conductivity Electrical conductivity Temperature capability Brittleness Molding with high filler content
Metals	Electrical conductivity Strength Temperature Thin Known fabrication techniques	Corrosion Poisoning of MEA Contact resistance Thermal conductivity Density Expensive alloys and coatings

Property Status for New Expanded Graphite FFPs

Material Property	DOE Target Need	Status
Electrical Conductivity	Plate	Meets DoE 2015 Target
Thermal Conductivity	Balance of Plant	Meets DoE 2015 Target
Contact Resistance	Plate	Meets DoE 2015 Target
Temperature (120 ºC)	MEA, Balance of Plant	R&D needed
Gas Impermeability	Plate	R&D needed
Mechanical Strength	Plate	R&D needed
Corrosion	Plate	Meets DoE 2015 Target
Ion Leachability	System Durability	R&D needed
Thickness	System Power Density	R&D needed
Manufacturability	Technology Viability	R&D needed
Flexibility	Plate	Meets DoE 2015 Target
Weight	Plate	Meets DoE 2015 Target
Cost	All	R&D needed

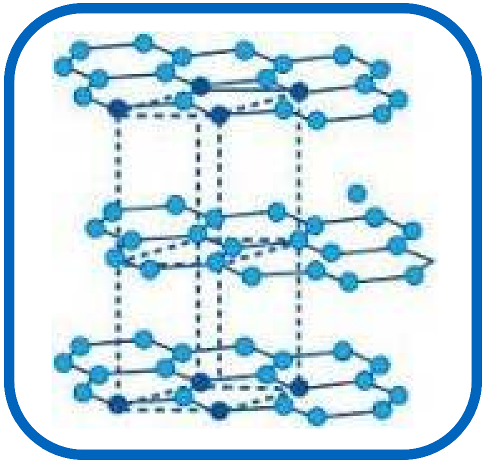
Approach to Meeting Remaining DOE FFP Targets

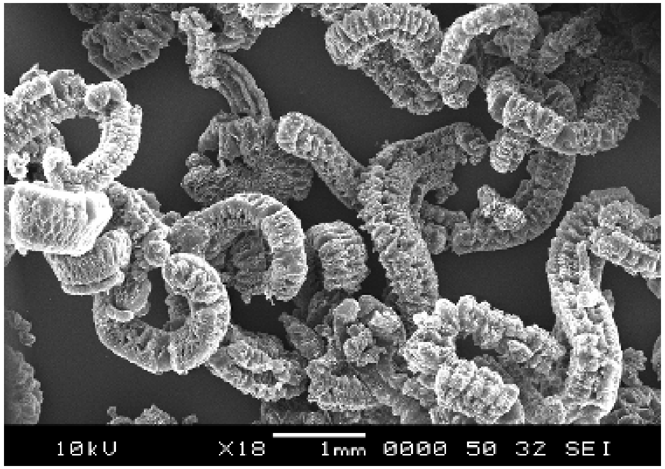
The “4 T’s”:

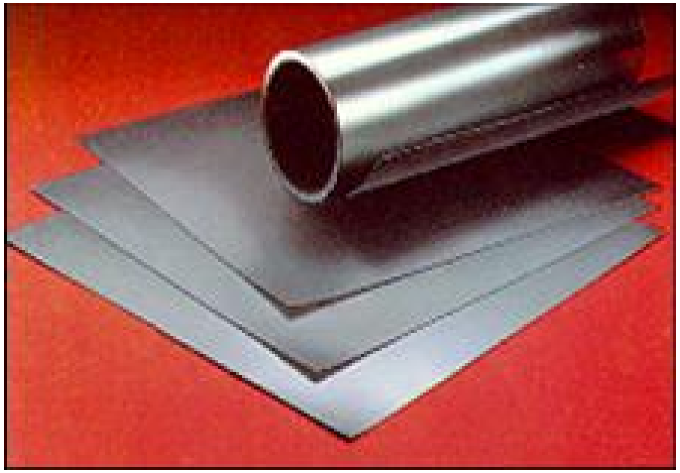
- Temperature
  - New higher temperature resin systems
- Thickness
  - Enabled through a combination of flake sourcing, flake processing, and composite processing
- Toughness
  - Enhanced through resin-reinforcement
- Throughput
  - Viable path to commercialization brought about by low cost manufacturing methodologies

Expanded Graphite

- Graphite flake is expanded by chemically “inserting” certain compounds between the graphite planes (intercalation)
- When exposed to heat, the chemicals inside the graphite decompose, forcing the graphite layers apart (exfoliation)

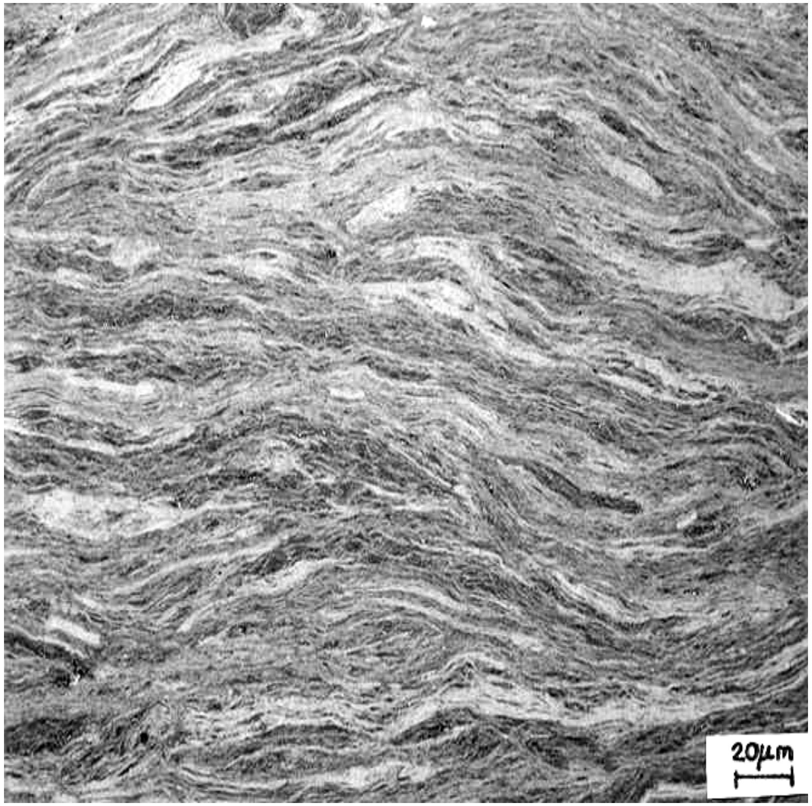






Expanded Graphite Sheet

- Calendaring, embossing, pressing
  - No binder required to make a continuous sheet
- Compression of expanded graphite re-aligns graphite layers
  - Structurally anisotropic
- Impregnable, Conformable, Sealable
- Light weight
- Thermally and Electrically Conductive – continuous graphite phase
- Near-zero CTE (Coefficient of Thermal Expansion) in-plane
- Chemically inert



Layers in compressed graphite sheet

Accomplishments – Task 1

Expanded Graphite Material Selection

Contributors: GrafTech, Ballard, Huntsman

Subtask 1.1: Define key flow field plate specifications with collaborators (Complete)

Subtask 1.2: Natural Graphite Selection (Complete)

- Natural graphite sources from a number of domestic and international suppliers were evaluated. Candidate flakes from these sources were selected.

Subtask 1.3: Intercalation Chemistry and Exfoliation Methods (In Progress)

- Design of experimental methodology
- Initial screening experiment complete. Preliminary materials selected for further study.
- Response surface experiment to identify interactions and final usable range of materials in progress.

Accomplishments – Task 2 (Complete)

Resin Identification and Selection

Contributors: GrafTech, Huntsman

Subtask 2.1: Resin Specifications Defined

- Based on key fuel cell performance characteristics
- Table of resin specifications developed

Subtask 2.2: Potential New Resin Chemistries Definition

- High performance epoxy and benzoxazine resins selected

Subtask 2.3: Part Release Chemistry Design

- Mold release chemistry incorporated into resin formulations

Subtask 2.4: Lab Scale Resin Samples Formulated and Neat Resin Properties Evaluated

- 9 Benzoxazine and 6 Epoxy formulations evaluated

Subtask 2.5: Resin Formulations Down select (Milestone)

- 2 Benzoxazine and 1 Epoxy resins down selected

Accomplishments - Task 2: Neat Resin Systems

				DMA Tg		TMA		TGA	
System	Catalyst	Gel Time @ 200°C	Softening Point	Tan Delta	Storage Modulus	Tg	CTE	Decomp Temp	Weight Loss
		s	°C	°C	°C	°C	µm/m°C	°C	%
Benzoxazine Resin									
1	No	>600	70.5	215	185	183	64	339	2.2
2	No	>600	84.8	171	137	128	82	319	1.9
2A	No	>600	Liquid	232	198	216	85	351	3.1
2B	No	>600	Liquid	225	183	195	159	343	2.6
2G	No	364.9	88.1	282	252	247	61	343	3.8
2H	No	440.9	74.6	282	255	261	52	347	3.8
3	No	>600	80.5	298	183	175	67	317	2.5
4	No	420	98	148	120	114	75	NA	NA
5	No	>600	87	183	148	104	65	NA	NA
Epoxy Resin									
1	Yes	30.3	Liquid	205.0	178.0	172.0	82.0	336.0	3.8
2	Yes	170/150°C	Liquid	208.0	191.0	184.0	81.0	309.0	3.5
3	Yes	100/150°C	Liquid	242.0	210.0	197.0	72.0	341.0	3.5
4	No	155/150°C	Liquid	156.0	125.0	NA	NA	NA	NA
5	Yes	31.3	Liquid	143.0	96.0	NA	NA	286.0	3.2
6	No	>600	Liquid	95.0	88.0	NA	NA	NA	NA
	Selected Systems								

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Accomplishments – Task 3 (Complete)

<u>Small-Scale Composite Preparation</u>

Contributors: GrafTech, Huntsman

Subtask 3.1: Prepare Flexible Graphite Mat for Resin Evaluation

Subtask 3.2: Preliminary Composite Preparation and Evaluation

- **Un-embossed expanded graphite-resin composites successfully fabricated**
- **Composite molding temperature defined**
- **Gas impermeability verified**
- **Resins selected for single cell and embossing studies (Milestone)**
  - **Epoxy resin system eliminated due to processing issues**

Subtask 3.3: Long-Term Testing of Selected Composite Samples

- **Flexural and tensile strength and modulus are improved or not significantly changed during both cycling and shock exposure for 2G resin system.**
- **The 2H system 3-ply samples show some degradation in strength**

Subtask 3.4: Composite Processing Variable Experimental Design Conducted

- **Key process variables identified**
- **Optimization study conducted on embossed plates**

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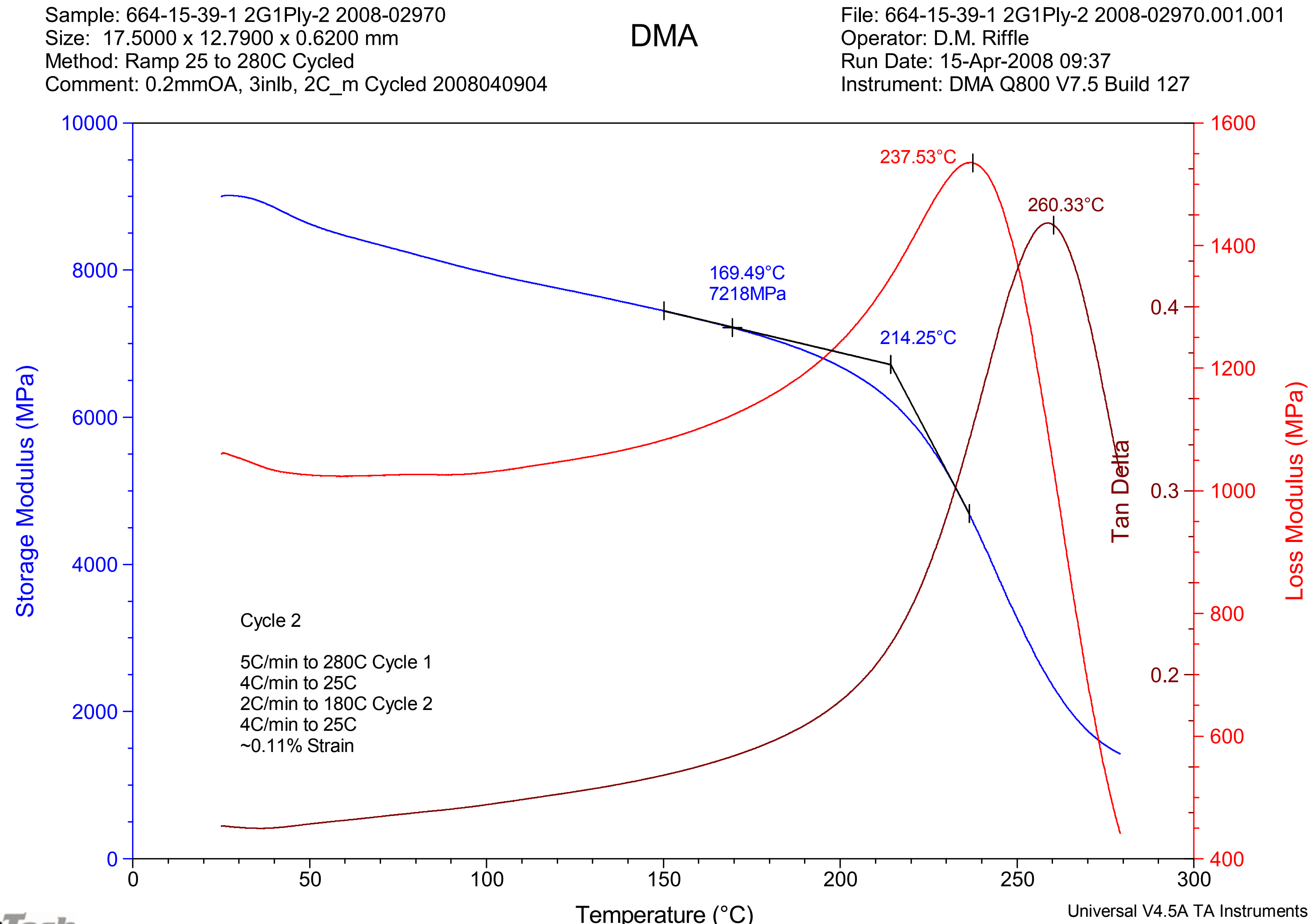
DMA Analysis of 2G Resin Graphite Composite



Subtask 3.2 Composite Property Comparison

Property	Method	Units	FFP Average	2G Resin Average	2H Resin Average
Bulk Density	ASTM C611	g/cm3	1.68	1.68	1.72
Thermal Conductivity (x,y)	ASTM D5470 Modified	W/m-K	275	286	294
Thermal Conductivity (z)	ASTM C714	W/m-K	4.67	4.03	4.03
Thermal Diffusivity	ASTM C714	cm^2/s	0.039	0.033	0.033
Electrical Resistivity (x,y)	ASTM C611	µΩm	7.8	8	11
Electrical Resistivity (x,y)	GTI Internal	µΩm	NA	10	9
Electrical Resistivity (z)	GTI Internal, 1-Ply	µΩm	NA	934	937
Contact Resistance	GTI Internal	$\mu\Omega cm^2$	NA	2.1	3.0
Electrical Conductivity (x,y)	GTI Internal	S/cm	1470	1002	1111
Electrical Conductivity (z)	GTI Internal, 1-Ply	S/cm	NA	10.7	10.7
Thermal Expansion Coefficient (x,y)	ASTM E1545	µm/m-K	1.31	0.95	0.98
Thermal Expansion Coefficient (z)	ASTM E1545	µm/m-K	97.2	81.8	74.1
Flexural Strength, -40 °C	ASTM D790	MPa	63.9	67.3	69.0
Flexural Strength, 23 °C	ASTM D790	MPa	57.5	58.7	61.8
Flexural Strength, 100 °C	ASTM D790	MPa	37.8	47.8	51.3
Flexural Strength, 120 °C	ASTM D790	MPa	NM	44.3	49.7
Tensile Strength, -40°C	ASTM D638	MPa	41.9	41.3	44.6
Tensile Strength, 23°C	ASTM D638	MPa	38.6	37.4	43.8
Tensile Strength, 100°C	ASTM D638	MPa	29.2	32.8	36.4
Tensile Strength, 120°C	ASTM D638	MPa	NM	32.6	37.4
NA - Not Available					
NM - Not Measured					

Subtask 3.3: Long-Term Environmental Cycling

USCAR - III Environmental Test Protocol (Modified)					
	Shock Test		Normal Cycle		
Cycles	100		40		
Step	1	2	1	2	3
Temperature, °C	125	-40	-40	87.5	125
Dwell, hrs	0.5		0.5		
Ramp Rate, °C/min	-328	328	4.25	1.25	-2.75
Hold Temp, °C	-40	125	87.5	125	-40
Relative Humidity, %	50	NA	80-90	NA	NA
Dwell, hrs	0.5	0.5	4	1.5	0.5

Subtask 3.3: Long-Term Environmental Testing

Resin	Ply	Flexural Modulus Before, Mpsi		Flexural Strength Before, psi		Flexural Modulus Cycle, Mpsi				Flexural Strength Cycle, psi				Flexural Modulus Shock, Mpsi				Flexural Strength Shock, psi			
		Avg	Std	Avg	Std	Avg	Std	Delta	t-Test	Avg	Std	Delta	t-Test	Avg	Std	Delta	t-Test	Avg	Std	Delta	t-Test
2G	1	2.88	0.200	8323	462	2.49	0.105	-14%	8.45	8870	229	7%	-5.20	2.22	0.139	-23%	13.4	8775	324	5%	-3.93
2G	3	3.06	0.059	8785	350	2.40	0.158	-22%	19.21	8610	290	-2%	1.89	2.35	0.081	-23%	34.8	8705	253	-1%	0.91
2H	1	3.07	0.196	8793	475	2.47	0.170	-20%	11.37	9138	160	4%	-3.37	2.26	0.174	-26%	15.0	8868	80	1%	-0.76
2H	3	3.36	0.112	9063	385	2.36	0.072	-30%	37.01	8770	184	-3%	3.36	2.35	0.180	-30%	23.4	8390	401	-7%	5.92
Paired t-Test (Before-After)									5.21				0.53				10.3				0.24
Critical t-value									2.447				2.447				2.447				2.447

Resin	Ply	Tensile Modulus Before, Mpsi		Tensile Strength Before, psi		Tensile Modulus Cycle, Mpsi				Tensile Strength Cycle, psi				Tensile Modulus Shock, Mpsi				Tensile Strength Shock, psi			
		Avg	Std	Avg	std	Avg	Std	Delta	t-Test	Avg	Std	Delta	t-Test	Avg	Std	Delta	t-Test	Avg	Std	Delta	t-Test
2G	1	3.91	0.573	4035	587	3.81	0.844	-2%	0.46	4443	602	10%	-2.38	3.31	0.442	-15%	4.03	4958	660	23%	-5.12
2G	3	4.90	0.319	5638	337	4.55	0.564	-7%	2.67	5483	412	-3%	1.43	4.67	0.379	-5%	2.35	5490	200	-3%	1.84
2H	1	5.71	0.639	5365	347	3.88	0.241	-32%	13.11	5263	455	-2%	0.88	3.46	0.127	-39%	16.89	5328	535	-1%	0.29
2H	3	5.21	0.387	6635	218	4.95	0.640	-5%	1.69	5535	585	-17%	8.64	4.40	0.424	-16%	6.93	5098	556	-23%	12.62
Paired t-Test (Before-After)									1.58				0.76				2.21				0.39
Critical t-value									2.447				2.447				2.447				2.447

	Improvement
	No Significant Change
	Degradation

Averages are based on results from 4 specimens, Statistical analysis based on α= 0.05

Accomplishments – Task 4 (Complete)

Machining and Embossment of Small-Scale Composites

Contributors: GrafTech, Huntsman, Ballard

Subtask 4.1: Fabricate New Composite Materials

Subtask 4.2: Validate Properties of New Graphite Containing Composites

- Mechanical testing results on resin flexible graphite composite samples in 1-, 3-, and 5 ply sheets were obtained.
- Results were equivalent or better then those for the incumbent GRAFCELL standard resin composite system.

Subtask 4.3: Machined Plates for Single Cell Testing

- Machined flow field plate design selected for use in single cell testing.
- Machining of the composite plates for single cell testing is completed.

Subtask 4.4: Design, Fabricate, and Evaluate Small Embossed Test Plates

- Flow field pattern based on a proprietary oxidant flow field die
- Plates were molded to a single plate thickness of less then 0.8 mm.
- Nitrogen gas permeability, in-plane and through plane electrical resistance, and dimensional processing changes (growth factors) have been measured on each plate.
- One of the graphite starting materials was eliminated from consideration based on significantly higher gas permeability results

Mechanical Testing t-Test vs. GRAFCELL

Ply	Temp., °C	Flexural Modulus, Mpsi		Flexural Strength, psi		Flexural Stain, in/in	
		2G	2H	2G	2H	2G	2H
1	-40	-1.00	-0.76	3.11	1.26	-5.67	-12.50
3	-40	7.65	9.26	1.72	8.34	-23.00	-44.00
5	-40	6.03	4.37	0.64	4.58	-6.50	-11.00
1	23	-1.12	0.80	1.36	3.31	-1.50	-2.00
3	23	38.57	24.64	1.51	2.71	-437.52	-951.84
5	23	6.76	78.00	-0.37	2.62	-7.50	-6.33
1	100	18.52	20.62	13.32	9.78	-45.50	-19.80
3	100	12.49	27.64	18.51	9.24	-27.33	-47.00
5	100	13.02	13.58	6.84	37.41	-12.00	-39.00
1	120	17.39	29.76	7.16	22.38	-26.25	-33.00
3	120	14.32	23.54	10.20	7.97	-43.00	-46.00
5	120	17.13	13.56	26.90	40.46	-70.00	-24.00
Critical Value		2.35	2.35	2.35	2.35	2.35	2.35
Paired t-Test (2G-2H)							
P-value		0.02		0.00		0.00	
Critical Value		0.05		0.05		0.05	
Code		Improved	Same	Degraded			

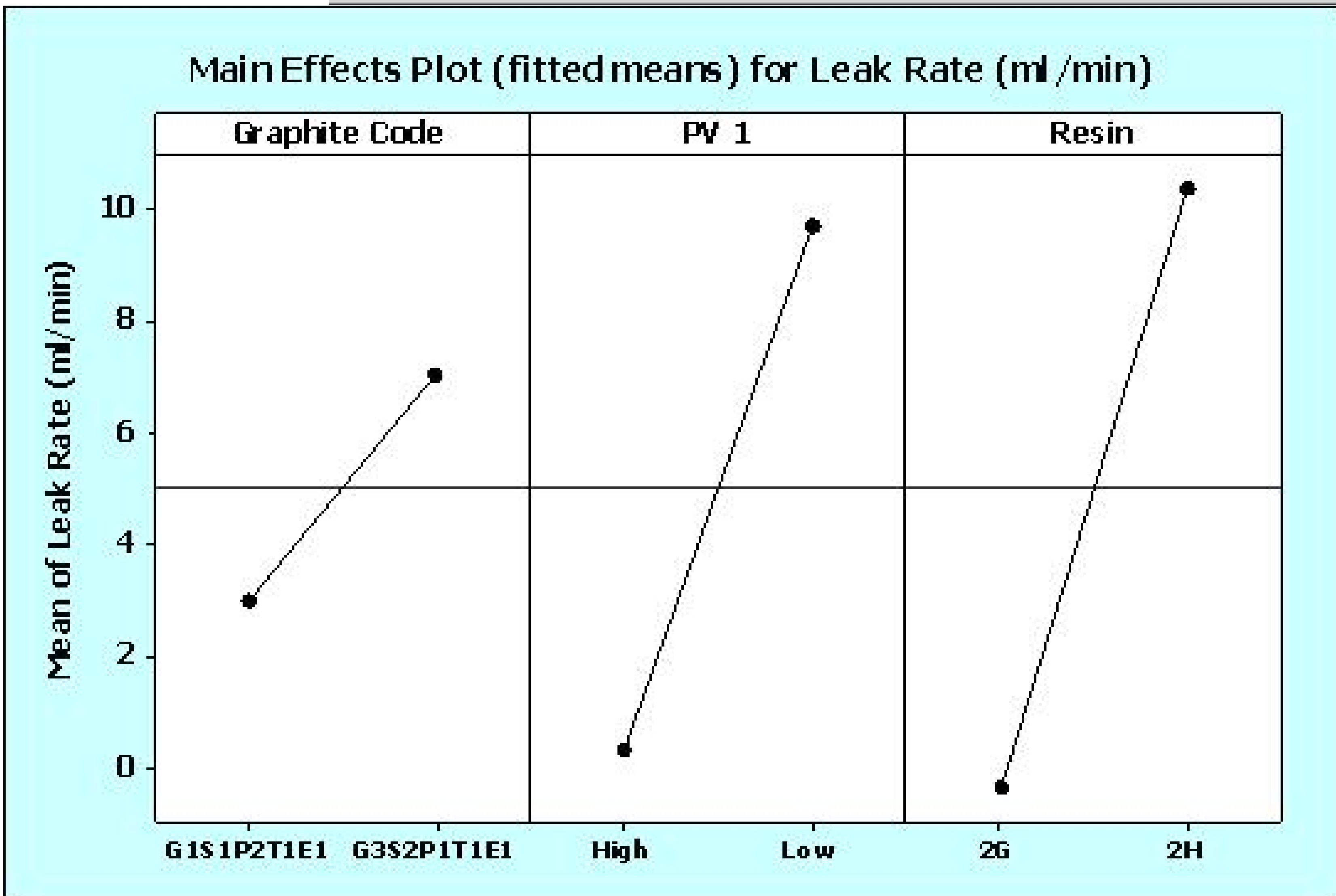
Table values are t-Test results for a 95% confidence interval with 3 degrees of freedom

Mechanical Testing t-Test vs. GRAFCELL

Ply	Temp., °C	Tensile Modulus. Mpsi		Tensile Strength, psi		Tensile Strain, %	
		2G	2H	2G	2H	2G	2H
1	-40	1.66	4.97	-0.80	4.76	-5.00	-2.73
3	-40	1.35	-1.69	-0.25	5.65	-4.14	-5.50
5	-40	-0.89	-9.14	3.39	0.99	-20.00	-8.75
1	23	2.60	8.03	-2.65	3.11	-6.67	-13.33
3	23	2.69	3.85	1.22	12.51	-274.16	-252.22
5	23	0.12	4.12	3.34	23.68	-3.03	-12.73
1	100	20.63	6.31	2.69	17.45	-11.49	-55.00
3	100	-1.47	-3.47	5.09	7.88	-14.26	-15.48
5	100	-0.23	-2.22	15.33	64.22	-12.75	-18.28
1	120	5.95	5.10	35.14	12.40	-19.74	-12.10
3	120	-20.29	-17.95	7.17	14.50	-16.34	-20.29
5	120	-2.49	-1.83	34.95	109.80	-13.41	-12.79
Critical value		2.353	2.353	2.353	2.353	2.353	2.353
Paired t-Test (2G-2H)							
P-value		0.21		0.00		0.92	
Critical Value		0.05		0.05		0.05	
Code		Improved	Same	Degraded			

Table values are t-Test results for a 95% confidence interval with 3 degrees of freedom

Subtask 4.4: ANOVA Results on Gas Permeability



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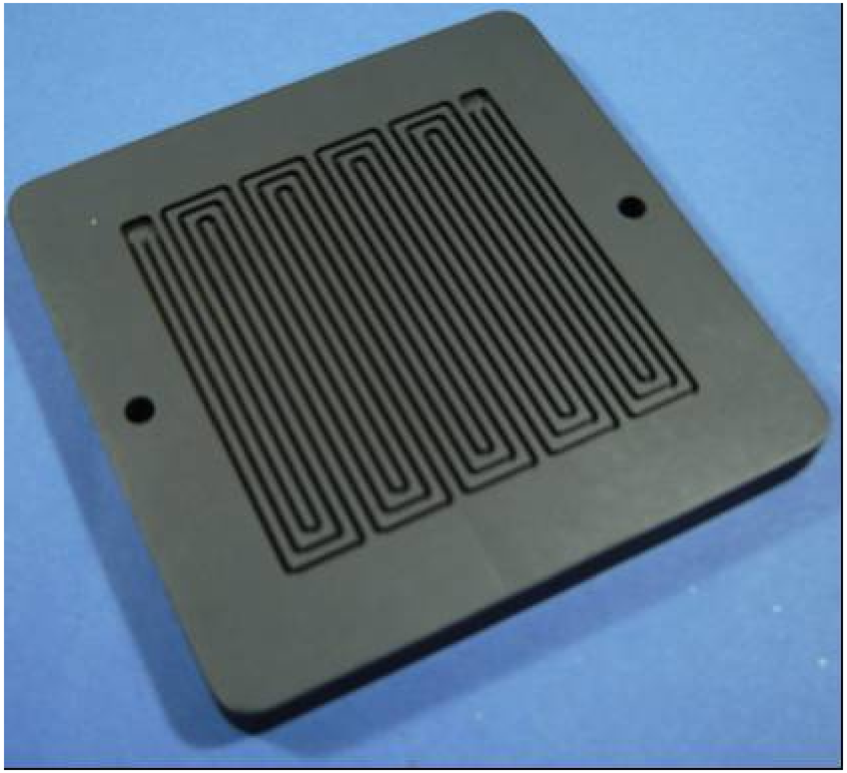
Benzoxazine Resin GRAFCELL Composite Plates



Machined GRAFCELL Composite Single Cell Flow Field Plate

Molded GRAFCELL Composite Corrugated Flow Field Oxidant Plate

Accomplishments – Task 5 (In Progress)

Single Cell Testing

Contributors: GrafTech, CWRU

Subtask 5.1: Select Fuel Cell Components Suitable for High Temperature Testing (Compete)

- High temperature cell components identified and procured
- Difficulty in obtaining high-temperature MEA delayed the start of single cell testing

Subtask 5.2: Develop Test Method for Analysis of Fuel Cell Leachate (In Progress)

- Test methods defined and analysis is in progress

Subtasks 5.3 - 5.5: Set up and Conduct 1000-hr Single Cell Test (In Progress)

- Single cell testing has begun
- 2G resin composite plate has operated for 300 hrs as of 4/11/08

Subtask 5.6: Post Test Plate Analysis (Not started)

Single Cell Testing

Protocol

- ETEK 1500 GDL
- 114 hrs @ 80 °C (70% RH)
- 86 hrs @ 120 °C (24% RH)
- Cells conditioned 24-48 hrs @ 80 °C
- Liquid samples collected.
- Cell Resistance:
  - After 114 hrs @ 80 °C: 0.23 Ohm cm^2
  - After 71 hrs @ 120 °C: 0.55 Ohm cm^2
  - After 86 hrs @ 120 °C: 0.54 Ohm cm^2

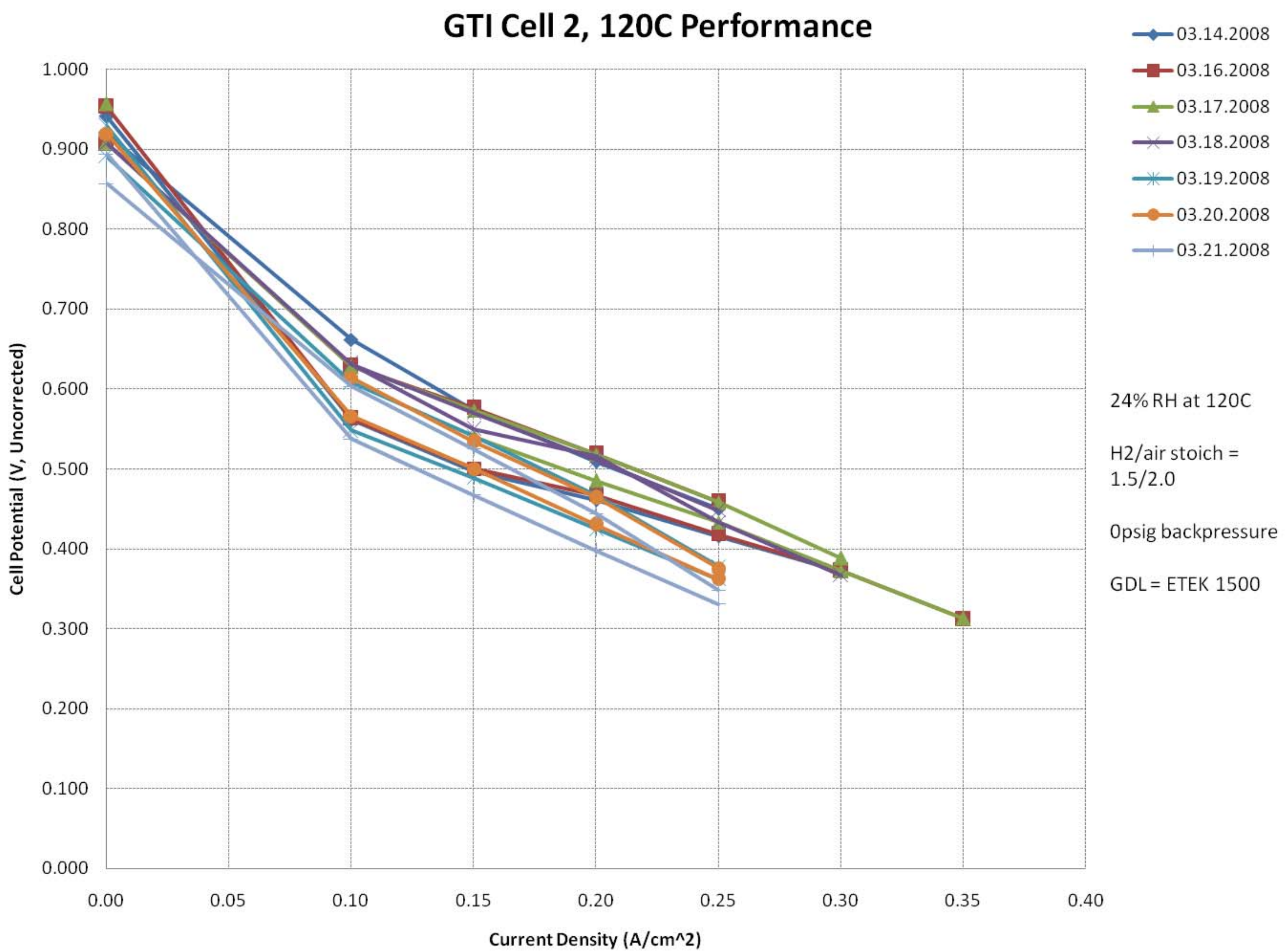
Results

- 2G plate: 352 hours operation at 120°C
- Typical MEA lasts approximately 100 hours.

Cell Operation Times

- Cell 1: 98.5 hours
- Cell 2: 117 hours
- Cell 4: 136.5 hours

Fuel Cell Performance High Temperature MEA



Accomplishments – Task 6 (In Progress)

Design and Manufacture Full-size Bipolar Plates

Contributors; GrafTech, Ballard

Subtask 6.1: Develop Test Methods and Test Plate Coolant Durability (Complete)

- Ballard has developed a glycol permeation test based on ASTM D739-99a to evaluate the permeation of ethylene glycol across the resin expanded graphite composite.
- Permeation testing has been completed on the 2G and 2H composites and the results are being reviewed. The data has been submitted to GrafTech for consideration to the overall material down-selection.

Subtask 6.2: Review of Existing Flow Field Plate Architectures (Complete)

- Ballard has reviewed the DoE requirements for this project task and evaluated existing Ballard fuel cell architectures as well as GrafTech material properties to arrive at a proposed design.

Subtask 6.3: Design Flow Field Plate Using Existing Architectures (in progress)

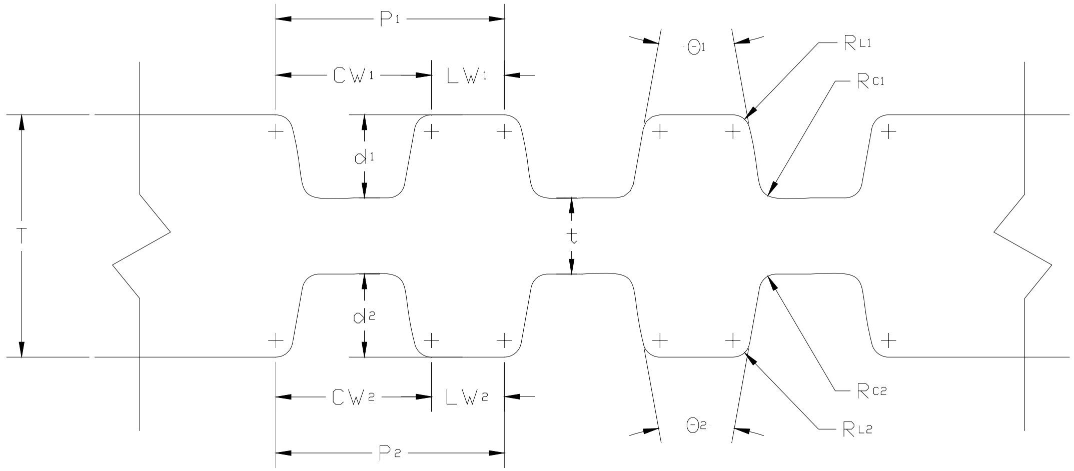
- Ballard has submitted to GrafTech a proposed fuel cell plate design in the form of electronic drawings and solid models files. The proposed design has incorporated known design features to aid in part formation during processing.
- The proposed design has a plate assembly thickness below 1.6mm and a plate active area greater than 250cm^2.

Subtask 6.4: Fabricate Full Size Embossing Die Set (Not Started)

Subtask 6.5 Emboss Full-size Bipolar Plates (In progress)

- Existing Press for use in full-size bipolar plate fabrication were evaluated and final selection has been made
- Final review and selection of graphite, resin and processing conditions has been conducted. 2G resin system and G3 graphite mat selected
- Manufacture of resin for full size plate production has been scheduled

Typical Flow Field Plate Design Parameters



Parameter Definition	Parameter
Web Thickness	t
Channel Depth	d_n
Landing Width	LW_n
Channel Width	CW_n
Pitch	P_n
Draft Angle	Θ_n
Landing Crown Radius	RL_n
Channel Root Radius	RC_n
Overall Thickness	T

Future Work – 2008 and early 2009

Task 6: Design Flow Field Plate Using Existing Architectures (Q2 & Q3 2008)

- Finalize plate design after reviews including minimum web thickness and volume uniformity
- Build small test tools to calculate growth factors and assess formability
- Final plate design review with material selection and growth factors incorporated
- Build full size embossing tool and initiate material fabrication
- Build leak check device and glue fixtures
- Commission glue equipment
- Build compression stack hardware including all supporting components
- Select Membrane Electrode Assembly (MEA) and modify seal equipment
- Fabricate, inspect and glue plates assemblies

Task 7: Short Stack Test of Full-size Plates (Q4 2008 & Q1 2009)

- Fabricate and seal MEAs
- Assemble inspected and glued plates with sealed MEAs in compression stack hardware
- Commission test station with duty cycle
- Conduct durability testing targeting 1000 hours on a 10 Cell stack
- Conduct freeze start testing
- Post test analysis, results and review including plate inspection
- Deliver Full Size Plate Stack to DOE

Task 8: Economic Assessment of New Technologies

- Q3 & Q4 2008

Task 9: Final Report Preparation

Summary

- All critical starting material evaluation and testing is complete
- Graphite mat and resin system for full size plate fabrication have been selected.
- New composite systems have been shown to have equivalent or improved dimensional stability and mechanical and thermal properties over the current GRAFCELL composite.
- Gas impermeability has been demonstrated to a single plate thickness of less then 0.8mm.
- Critical processing parameters for plate embossing have been identified and optimized.
- Basic plate architecture has been identified.
- Production press for fabrication of full-size plates has been identified, evaluated, and certified for use.
- Preliminary leachate, glycol and single cell testing results are positive or do not indicate any significant problems with cell operations at elevated temperature.
- Program is on schedule to produce full-size flow field plates for high temperature short stack testing by Ballard in early 2009